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Cut and Suture Support on Volumetric Models in the CyberMed Framework

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Abstract

The need of applications for realistic training to medical professionals motivated the development of the framework CyberMed. Since 2006, this framework provides a set of features that allow users to freely build interactive virtual environments for realistic medical training. Thus, simulations composed by 3D visualization and interaction with haptic feedback can be created for different areas of medicine. In order to allow using data obtained from real exams, such as CT and MRI, the CyberMed had its kernel recently expanded. Now the framework enables working with volumetric data to build more realistic medical simulations. The aim of this paper is to present this process of expansion realized in a cooperation work between two countries, emphasizing the new possibilities offered by this integration for further works related to simulations with cut and suture of tissues.

Keywords: Simulation; volumetric model; virtual reality; data structure

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1. Introduction

Surgical simulation offers the promise of enhanced medical training and education. It can provide a more realistic learning environment for surgeons than many of the traditional methodologies such as plastic models, cadavers, or actual patients. It can also increase the variability of pathologies presented to the student in the continuing education process, who can practice on a particular pathology as many times as he feels necessary. Cutting and suturing are very common and important tasks within surgery. They need to be done accurately, following the path traced out by the user as close as possible, while maintaining the stability and efficiency of the overall simulation. An important issue in cutting and suturing simulation is focusing on increasing the realism of modeling soft tissues. In general, there are two methods: surface-based models and volume-based models. Surface models that have been implemented range from continuous, snake-based models, to discrete mass spring models based on triangular meshes. The problem with all surface-based models, when used to simulate tissue with interior structure, is that they do not explicitly model the interior. Therefore, complex interactions between the tissue surface and the interior structure cannot be modeled. Volume-based models can simulate interior structure because they encode the entire object, and model the interactions between the interior structure and the exterior of the object. Therefore they are more powerful, although the computation is more complex and expensive.

The use of frameworks for development simulation had been the focus of several projects, some of them specifically for medical applications [1,2,3,4,5]. Some advantages of using those frameworks are reuse of code, fast integration of tasks and unified code for hardware support. In general, they allow development of medical simulations that are composed by 3D models import, interactive deformation, stereoscopic visualization, collaborative simulation, etc. However, only a few frameworks provide support for user assessment, volumetric approaches and visual programming interfaces.

Since the year of 2006 an open-source project called CyberMed has been developed. The focus of this project is the development of a framework for programming of medical simulators based on virtual reality [4]. In the year of 2008 the first version was launched with support for 3D models reading, collision detection, deformation, stereoscopic visualization, haptics interaction and user assessment. Since then, the project has been expanded with new features and nowadays has new components to support network communication, collaborative tasks and optical and magnetic, besides new assessment methods. Figure 1 shows the components of the framework.

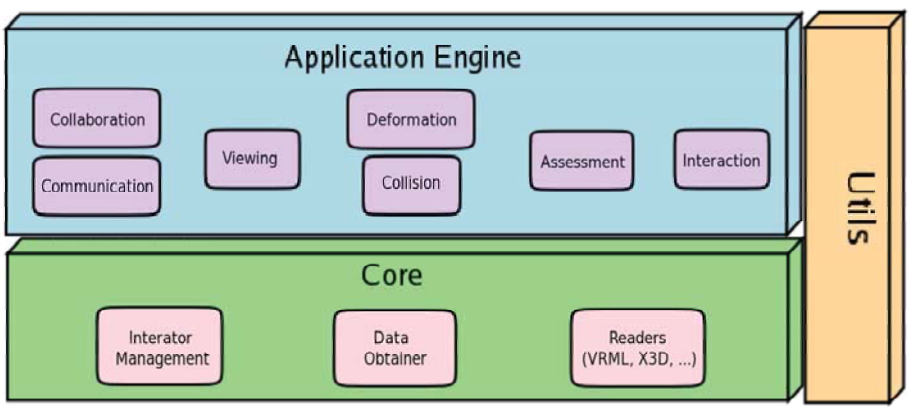

Fig. 1. CyberMed components

Three modules compose the CyberMed framework: Application Engine, Utils and Core. The Application Engine module has the components that can integrate a medical simulation. These components are independent and can be used separately or grouped. The Core module has the models readers, data structure and managing of interators and tasks. The Utils module has mathematical operators and functions that are used by the other modules. From the three main problem detected in the frameworks for medical simulators development (user assessment, volumetric approaches and visual programming interfaces), user assessment is provided by CyberMed. The absence of a graphical interface for programming directs the use of the framework for programmers, but there is an initiative to integrate to CyberMed a system for visual programming to achieve non-programmers users [6]. In order to allow volumetric approaches, an expansion of the Cybermed was proposed. Since all data related to the models used in simulation are managed by a data structure (DS) in the Core module, the replacement or expansion of this DS must be considered to support cut and suture in a realistic way. This paper presents the efforts to expand the data structure of CyberMed and point out the benefits expected.

2. The Mate Face Data Structure

Topological Data Structures (DS) seek to index mesh elements in order to represent the incidence and adjacency relations between these elements, while ensuring efficient access to its information [7,8]. Many DS described in the literature aim to index the data as to facilitate the access of neighborhood relations and the element search mechanisms in construction, transformation or storage of meshes [9], and still allowing the adaptive control procedures.

The Mate Face (MF) DS is a topological structure developed to expand the Opposite Face (OF) (proposed by Mario Lizier [10]) in terms of the representation type of elements and types of 2D or 3D meshes. Similarly to the OF structure, the development of this structure was focused on two main features: ease of use and flexibility. Because of this and to support users, the use of a standard documentation for its code was required, making the DS more understandable.

In subsections 2.1 and 2.2, we will detail the MF structure main features and its type of mesh data support.

2.1. Mesh Data Support

A major goal of the MF structure is to represent both bidimensional (planar or surface) and three-dimensional (volumetric) meshes, moreover, these meshes can be simple or composite (hybrid) [11]. In this case, the main difference to the OF structure is that the MF structure not only is able to represent triangular and tetrahedron meshes, but also quadrilateral and hybrid surface meshes, and hexahedron, prismatic and pyramided volumetric meshes. Another major difference between the two structures is that the MF structure represents the edges and faces explicitly.

As in the OF structure, all classes of MF structure depend on templates parameters that need to be defined at the time of its statement. This feature makes the DS more flexible and able to represent different types of meshes with associated data to its different components, simply by changing the template parameter definition.

Each class that represents a particular component of the mesh requires a different set of template parameters. The use of the profile (trait) was then proposed to make the use of templates more practical, as it can be grouped into a single set all the parameters required for all classes of the structure. This profile should contain all the types used in all classes this way, each class is responsible for choosing the types it uses.

2.2. Main Features

An important feature taken into account in the design of the MF structure is to abstract as much as possible, the necessary knowledge about topological DSs [11]. Therefore, a simple and efficient interface is necessary, and also a complete documentation of its structure (classes, attributes, methods, etc.). In this way, it can be used without the need of the knowledge of its internal operation.

It is worth mentioning again that the use of profiles is very important to make the MF structure flexible. In its basic form, the MF structure has only enough data for visualization applications. So, in case of a specific application, a profile can be created to represent a mesh with all additional data needed. It is necessary to create a new class (where the data will be assigned) that inherits the base class of its respective MF. In applications where there is no need for assigning values to the meshes components, you can reduce memory consumption with implicit in the representations. All this is possible due to the flexibility of the MF.

3. Data Structure Migration

CyberMed 2.0 uses the OF in its Core module. The OF structure is not only limited in regards to mesh type representation (only represents triangular or tetrahedral meshes), but also in regards to mesh component representation (doesn't explicitly represent edge nor face). These limitations might compromise future extensions of the CyberMed system, for example, some elastic mesh applications might need additional information related to the edge component of a mesh.

Due to the limitations of OF structure, it was decided to migrate to MF structure. Even though a lot of internal changes to the CyberMed system were needed, these limitations are too compromising for future expansion. But, it should be noted, that the external structure of the CyberMed system was not drastically changed, in other words, the difference of use between versions is not critical.

3.1. Main Changes Caused by the Migration

The major problem that comes with the DS migration in the CyberMed system was that all of its classes that depend on the previous DS need to be adapted. Fortunately, due to similarities between both DS, most of the differences were related to different class names.

The most complex changes were done to the Core and Parameters classes (shell classes). These classes are responsible for most of the preliminary data generation for the applications. One issue encountered was due to the fact that the CyberMed system earlier versions only supported triangular surface meshes. Taking this into account, the shell classes were redesigned to support volumetric meshes when these types of meshes are used.

The general idea for the support of volumetric meshes in the CyberMed system is that two instances of each volumetric mesh is stored in the system: the full mesh and the surface of the volumetric mesh. Basically, while the system reads a volumetric mesh file and stores its data, the system's shell classes obtain its surface (as a different mesh instance) and stores it.

In the specific case of the application in this work, the volumetric data will be used for cut and suture operations where the internal information is need. Since the collision and visualization only need the surface of the mesh to do their operations, this is where the surface instance comes in handy. It should be noted that, while the cut and suture operations are happening, the surface of the volumetric instance is deformed, the surface instance is automatically updated to show the resulting deformations.

4. Results

In order to demonstrate the volumetric support of the mate face data structure, a bunny model was tested with the CyberMed with the MF integrated. The bunny showed in Figure 2 comes from vtk file, which has 49918 volumetric meshes and 198607 vertices. Now two types of file formats are supported by CyberMed: the wrl file format (Virtual Reality Modeling Language - VRML) for surface model and the vtk file format (Visualization Toolkit) for volumetric model. Realistic graphical display, collision detection, and haptic force feedback have also been implemented in CyberMed based on volumetric model.

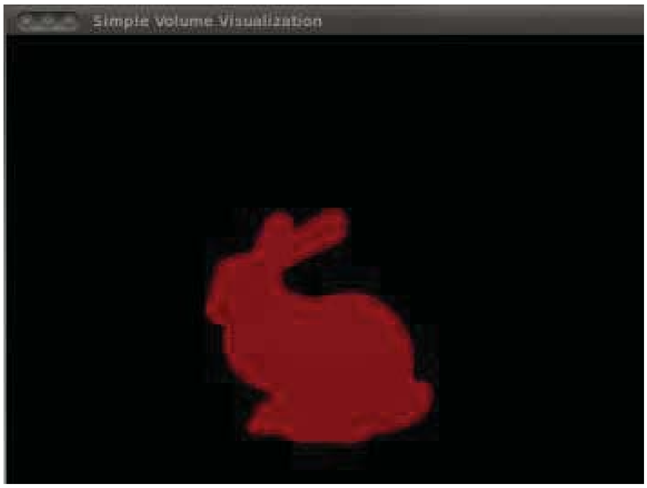

Fig. 2. Volumetric support in CyberMed

The future work will be mainly focused on haptic-based cutting and suturing using volumetric approaches. As the apparently most common actions during any surgery, cutting and suturing are also the most complex tasks since they involve precise force feedback, complex tissue surface properties, nonlinear tissue dynamics, interaction with deformable tissue and organs, puncturing and thread stretching, etc., volumetric models support a more realistic and physical approach for these cutting and suturing simulations [12]. Some improvements in lighting also have been implemented.

The new version with MF is expected to be available on 2012, July at the project site: http://cybermed.sourceforge.net. All research groups interested in the CyberMed project are invite to contribute.

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